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BACKGROUND OF THE INVENTION

[0002] A trench MOSFET (metal-oxide-semiconductor field-effect transistor) is a transistor in which the channel is formed vertically and the gate is formed in a trench extending between the source and drain. The trench, which is lined with a thin insulator layer such as an oxide layer and filled with a conductor such as polycrystalline silicon (also known as polysilicon), allows less constricted current flow and thereby provides lower values of specific on-resistance. Examples of trench MOSFET transistors are disclosed, for example, in U.S. Patent Nos. 5,072,266, 5,541,425, 5,866,931 and 6,031,265, the disclosures of which are hereby incorporated by reference.

[0004] A typical MOSFET device includes numerous individual MOSFET cells that are fabricated in parallel within a single chip (i.e., a section of a semiconductor wafer). Hence, the chip shown in Fig. 1 contains numerous hexagonal-shaped cells 31 (portions of five of these cells are illustrated). Cell configurations other than hexagonal configurations are commonly used, including square-shaped configurations. In a design

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[0007] (It is also noted that, for the specific design illustrated in Fig. 1, the p+ central portion of the p body region 27 extends to a depth d_{max} below the surface of the epitaxial layer that is greater than the trench depth d_{tr} for the transistor cell so that breakdown

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According to an embodiment of the invention, a trench MOSFET transistor device is provided, which comprises: (a) a silicon substrate of first conductivity type; (b) a silicon epitaxial layer of first conductivity type over the substrate, the epitaxial layer having a lower majority carrier concentration than the substrate; (c) a trench extending into the epitaxial layer from an upper surface of the epitaxial layer; (d) an insulating layer lining at least a portion of the trench; (e) a conductive region within the trench adjacent the insulating layer; (f) a body region of second conductivity type provided within an upper portion of the epitaxial layer and adjacent the trench; (g) a source region of first conductivity type provided within an upper portion of the body region and adjacent the trench; (h) an upper region of second conductivity type within an upper portion of the body region and adjacent the source region, the upper region having a higher majority carrier concentration than the body region; and (i) a source contact region disposed on the epitaxial layer upper surface, wherein the source contact region comprises a doped polycrystalline silicon contact region in electrical contact with the source region as well as an adjacent metal contact region in electrical contact with the source region and with the upper region.

[0013] The metal contact region preferably comprises aluminum. The doped polycrystalline silicon contact region is preferably an N-type polycrystalline silicon region, and more preferably an N-type polycrystalline silicon region having a doping concentration ranging from 5×10^{19} to $1 \times 10^{20} \text{ cm}^{-3}$. The doped polycrystalline silicon contact region is also preferably substantially triangular in cross-section.

[0014] The trench MOSFET transistor device preferably further comprises an insulating region (e.g., borophosphosilicate glass region) that is disposed over the conductive region and extends above the epitaxial layer upper surface. In this case, the doped polycrystalline silicon contact region is preferably positioned laterally adjacent to the insulating region, preferably has a thickness that is greatest adjacent the insulating region, and preferably has an upper surface that slopes away from the insulating region.

[0015] In some embodiments, the trench MOSFET transistor device further comprises an additional region of second conductivity type, which has a higher majority carrier concentration than the body region and which is immediately below the upper region.

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[0016] In various embodiments: (a) the trench MOSFET transistor device preferably comprises a plurality of transistor cells, for example, of square geometry or hexagonal geometry, (b) the insulating layer is preferably a silicon oxide layer, (c) the conductive region preferably comprises doped polycrystalline silicon, and/or (d) the first conductivity type is preferably N-type conductivity and the second conductivity type is preferably P-type conductivity (more preferably, the substrate is an N+ substrate, the epitaxial layer is an N epitaxial layer, the body region is a P region, the source region is an N+ region, and the upper region is a P+ region).

[0017] According to another embodiment of the invention, a trench MOSFET transistor device is provided, which comprises: (a) an N-type silicon substrate; (b) an N-type silicon epitaxial layer over the substrate, wherein the epitaxial layer has a lower majority carrier concentration than the substrate; (c) a trench extending into the epitaxial layer from an upper surface of the epitaxial layer; (d) a silicon oxide insulating layer lining at least a portion of the trench; (f) a doped polycrystalline silicon conductive region within the trench adjacent the insulating layer; (g) a P-type body region provided within an upper portion of the epitaxial layer and adjacent the trench; (h) an N-type source region provided within an upper portion of the body region and adjacent the trench; (i) a P-type upper region within an upper portion of the body region and adjacent the source region, the upper region having a higher majority carrier concentration than the body region; (j) a borophosphosilicate glass insulating region disposed over the conductive region, the insulating region extending above the epitaxial layer upper surface; and (k) a source contact region disposed on the epitaxial layer upper surface and laterally adjacent the insulating region, wherein the source contact region comprises a doped polycrystalline silicon contact region having N-type doping that is in electrical contact with the source region, as well as an adjacent metal contact region that is in electrical contact with both the source region and the upper region.

[0018] According to another embodiment of the invention, a method of forming a trench MOSFET transistor device is provided. The method comprises: (a) providing a silicon substrate of a first conductivity type; (b) depositing a silicon epitaxial layer of the first conductivity type over the substrate, the epitaxial layer having a lower majority carrier concentration than the substrate; (c) etching a trench extending into the epitaxial layer from an upper surface of the epitaxial layer; (d) forming an insulating layer that

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lines at least a portion of the trench; (e) forming a conductive region within the trench and adjacent the insulating layer; (f) forming a body region of a second conductivity type within an upper portion of the epitaxial layer and adjacent the trench; (g) forming a source region of the first conductivity type within an upper portion of the body region and adjacent the trench; (h) forming an upper region of second conductivity type within an upper portion of the body region and adjacent the source region, the upper region having a higher majority carrier concentration than the body region; and (i) forming a source contact region on the epitaxial layer upper surface, wherein the source contact region comprises both a doped polycrystalline silicon contact region in electrical contact with the source region and an adjacent metal contact region in electrical contact with the source region and with the upper region.

[0019] Preferably, the method further comprises forming an insulating region (e.g., borophosphosilicate glass region) that is disposed over the conductive region and extends above the epitaxial layer upper surface. In this case, the source contact region is preferably formed by a process comprising: (a) providing a layer of doped polycrystalline silicon over the insulating region and the epitaxial layer upper surface; (b) etching the layer of doped polycrystalline silicon (e.g., by reactive ion etching) until a portion of the epitaxial layer upper surface is exposed and a portion of the doped polycrystalline silicon remains adjacent the insulating region, and (c) depositing a metal layer over the insulating region, the epitaxial layer upper surface, and the remaining portion of the doped polycrystalline silicon adjacent the insulating region.

[0020] One advantage of the present invention is that a trench MOSFET device is provided in which the contact resistance of the device is decreased.

[0021] Another advantage of the present invention is that a trench MOSFET device is provided in which the effective source contact area of the device is increased.

[0022] Another advantage of the present invention is that a trench MOSFET device is provided having improved drain-source resistance.

[0023] The above and other embodiments and advantages of the present invention will become immediately apparent to those of ordinary skill in the art upon review of the Detailed Description and Claims to follow.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Fig. 1 is a schematic partial cross-sectional view of a trench MOSFET device in the prior art.

[0025] Fig. 2 is a schematic partial cross-sectional view of a trench MOSFET device in the prior art.

[0026] Fig. 3A is a schematic partial cross-sectional view of a trench MOSFET device, in accordance with an embodiment of the present invention.

[0027] Fig. 3B is a schematic partial cross-sectional view of a trench MOSFET device, in accordance with another embodiment of the present invention.

[0028] Figs. 4A through 4D are schematic partial cross-sectional views illustrating a method of making a trench MOSFET device like that of Fig. 3A, in accordance with an embodiment of the present invention.

[0029] Figs. 5A and 5B are schematic partial cross-sectional views illustrating a method for varying the width of the doped polycrystalline silicon contact portions within a trench MOSFET device, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0030] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the present invention are shown. This invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein.

[0031] Fig. 3A illustrates a trench MOSFET in accordance with an embodiment of the present invention. In the trench MOSFET shown, an epitaxial layer 201 is provided on an N⁺ substrate 200.

[0032] The N⁺ substrate 200 in this specific example is a silicon substrate having a thickness ranging, for example, from 10 to 25 mils and a net doping concentration ranging, for example, from 1×10^{19} to 1×10^{20} cm⁻³.

[0033] An N region 202 is found in the lower portion of the epitaxial layer 201,

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which is a silicon layer in this example. In this example, N region 202 has a thickness ranging, for example, from 2 to 8 microns and a net doping concentration ranging, for example, from 1×10^{15} to $5 \times 10^{16} \text{ cm}^{-3}$.

[0034] P body regions 204b are found in the middle portion of epitaxial layer 201. In the example shown, these P-body regions 204b extend, for example, to a depth of 1 to 2 microns from the upper surface of the epitaxial layer 201 and have a net doping concentration ranging, for example, from 1×10^{15} to $5 \times 10^{16} \text{ cm}^{-3}$.

[0035] Shallow P+ regions 204s are found in an upper portion of the epitaxial layer 201. In the example shown, these shallow P+ regions 204s range, for example, from 0.2 to 0.4 microns in depth from the upper surface of the epitaxial layer and have a net doping concentration ranging, for example, from 1×10^{15} to $1 \times 10^{17} \text{ cm}^{-3}$. Deep P+ regions 204d are also provided below the shallow P+ regions 204s. In the example shown, these deep P+ regions 204d extend, for example, to a depth of 0.4 to 1 micron from the upper surface of the epitaxial layer 201 and have a net doping concentration ranging, for example, from 1×10^{14} to $1 \times 10^{16} \text{ cm}^{-3}$. Although not wishing to be bound by theory, and as previously discussed in U.S. Patent No. 6,031,265, it is believed that the deep P+ regions 204d reduce the parasitic resistance of the cell. The shallow P+ regions 204s further reduce the contact resistance at the metal contact portion 218.

[0036] Trenches formed within the epitaxial layer 201 are lined with an insulator 210, typically an oxide insulator such as silicon oxide, and are filled with conductor 211, typically doped polycrystalline silicon, providing the gate electrode function of the device. The trenches extend, for example, to a depth of 1.5 to 3 microns from the upper surface of the epitaxial layer 201 and are, for example, 0.4 to 0.8 microns in width. Where silicon oxide (typically silicon dioxide) is used as the insulator 210, it can be for example, 500 to 700 Angstroms thick. Where polycrystalline silicon is used as the conductor 211, it can have a resistivity of, for example, 1 to 15 ohm/sq. The regions between the trenches are frequently referred to as "mesas" or "trench mesas", based on their shapes. These regions range, for example, from 1 to 5 microns in width.

[0037] The trench MOSFET device of Figure 3A also contains N+ source regions

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212, which extend, for example, to a depth of 0.3 to 0.5 microns from the epitaxial layer 201 surface and have net doping concentrations ranging, for example, from 1×10^{19} to $1 \times 10^{20} \text{ cm}^{-3}$.

[0038] The source contact in the device of Fig. 3A contains both a metal contact portion 218 and doped polycrystalline silicon contact portions 215. Insulating regions, such as BPSG (borophosphosilicate glass) regions 216, prevent the doped polycrystalline silicon regions 211 associated with the gate electrodes from being shorted to the N+ source regions 212 through the source contact.

[0039] The metal contact portion 218 of the source contact is in electrical contact with both the source regions 212 and with the shallow P+ regions 204s. Aluminum and copper are preferred materials for the metal contact portion 218.

[0040] The doped polycrystalline silicon contact portions 215 of the source contact are in electrical contact with the source regions 212. N-type dopants, such as arsenic, are preferred. Preferred doping concentrations for the doped polycrystalline silicon contact portions 215 range from 1 to 10 ohm/sq.

[0041] Although doped polycrystalline silicon has a higher bulk resistivity than metal, the overall resistance associated with the gate contact of Fig. 3A is nonetheless reduced relative to the case where the polycrystalline silicon contact portions 215 are absent. Without wishing to be bound by theory of operation, this is believed to be the case for the following reasons:

[0042] o Due to the fact that the polycrystalline silicon contact portions 215 and the source regions 212 are formed of the same material (i.e., silicon), the contact resistance between these regions is very low, much lower than that associated with a metal-silicon interface. This is particularly true where the doping concentration of the source regions 212 is low at the metal-silicon interface (e.g., less than $4 \times 10^{19} \text{ cm}^{-3}$), a situation that is commonly encountered in a design like that shown in Fig. 3A due to diffusion during processing. Such low doping concentrations prevent the formation of an effective ohmic contact between the metal and the silicon. By providing the relatively highly doped polycrystalline silicon contact portions 215, however, an effective ohmic contact is achieved between the metal contact portion 218 and the

polycrystalline silicon contact portions 215. At the same time, an effective contact exists between the polycrystalline silicon contact portions 215 and the sources 212 for the reasons just mentioned.

[0043] o The contact design of Fig. 3A is also advantageous because the interfacial area between metal and silicon is increased, and hence the contact resistance is decreased. For example, referring to Fig. 3A, metal and silicon (either polycrystalline silicon or single crystal silicon) form interfaces as indicated by numerals 217b and 217c. In the absence of the polycrystalline silicon contact portions 215, the metal and silicon would form interfaces as indicated by numerals 217a and 217c. Interfaces 217b are larger than interfaces 217a. (This can be understood by realizing that the polycrystalline silicon contact portions 215 are substantially triangular in cross section. Hence, interface 217a can be thought of as the leg of a right triangle, and interface 217b can be thought of as the hypotenuse of the same right triangle. However, since interface 217b is bowed, the effect is even more pronounced.) As a result, the interfacial area between metal and silicon is increased from that which would be observed in the absence of polycrystalline silicon contact portions 215.

[0044] To complete the device, a separate metal gate contact (not shown) is typically connected to the gate runner portion of the polycrystalline silicon 211 located outside of the region of the trench MOSFET cells. A metal drain contact (not shown) is also typically provided adjacent the N+ substrate 200.

[0045] Another embodiment of the present invention is illustrated in Fig. 3B. Fig. 3B is essentially the same as Fig. 3A, except that the deep P+ regions 204d are eliminated.

[0046] A method will now be described for manufacturing a trench MOSFET like that shown in Fig. 3A, in accordance with an embodiment of the present invention. Turning now to Fig. 4A, an epitaxial layer 201 (N doped) is grown on an N+ doped substrate 200. The N+ doped substrate 200, for example, can be 10 to 25 mils thick and have a net n-type doping concentration of from 1×10^{19} to $1 \times 10^{20} \text{ cm}^{-3}$. The epitaxial layer 201 can have, for example, a net N-type doping concentration of 1×10^{15} to $5 \times 10^{16} \text{ cm}^{-3}$.

[0047] A P body region 204b is then formed in the epitaxial layer 201 by implantation and diffusion. For example, the epitaxial layer 201 may be implanted with boron at 20 to 50 keV with a dosage of 5×10^{13} to 1×10^{14} , followed by diffusion at 1100 to 1200 degrees C for 30 to 120 minutes. This produces a P body region 204b, which extends, for example, to a depth of 1 to 2 microns from the upper surface of the epitaxial layer 201 and has a net p-type doping concentration of 1×10^{15} to $5 \times 10^{16} \text{ cm}^{-3}$. After this step, a portion of the epitaxial layer 201 remains n-type (i.e., N region 202), which is, for example, 2 to 8 microns thick. N region 202 generally maintains the n-type doping concentration that is noted above for epitaxial layer 201. A patterned trench mask layer 203 is then formed. The resulting structure is shown in Fig. 4A.

[0048] Trenches are then etched through apertures in the patterned trench mask 203, for example, by a dry anisotropic etching step. Trench depths in this example are about 1.5 to 3 microns. Discrete P body regions 204b are established as a result of this trench-forming step. A sacrificial oxide layer is typically grown within the trench and removed as is known in the art. An oxide layer 210, which is preferably 500 to 700 Angstroms thick, is then grown over the trench bottom, for example, by wet or dry oxidation at 900 to 1100 °C for 30 to 60 minutes. Portions of this oxide layer 210 ultimately form the gate oxide regions for the finished device.

[0049] The surface of the structure is then covered, and the trenches are filled, with a polycrystalline silicon layer, preferably using CVD. The polycrystalline silicon is typically doped N-type to reduce its resistivity. N-type doping can be carried out, for example, during CVD with phosphorous chloride or by implantation with arsenic or phosphorous. The polycrystalline silicon layer is then etched, for example, by reactive ion etching. The polycrystalline silicon layer within the trench segments is commonly slightly over-etched due to etching uniformity concerns, and the thus-formed polycrystalline silicon gate regions 211 typically have top surfaces that are 0.1 to 0.2 microns below the adjacent surface of the epitaxial layer 204b. The resulting structure is shown in Fig. 4B.

[0050] A patterned source mask 205 is provided over the structure. N+ source regions 212 are then formed in upper portions of the epitaxial layer by implanting an N-dopant, such as arsenic or phosphorous, through apertures in the source mask.

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Implantation is preferably conducted through an implant oxide to avoid implant-channeling effects, implant damage, and heavy metal contamination during formation of the source regions. The structure can be implanted, for example, with phosphorous at 100 to 130 keV with a dosage of 5×10^{15} to 8×10^{15} . The resulting structure is shown in Fig. 4C, with the implanted regions being designated by dashed lines.

[0051] The source mask is then stripped. An insulating layer, preferably a BPSG (borophosphosilicate glass) layer is then deposited over the entire structure, for example, by PECVD. The BPSG is then subjected to a reflow step, for example, at 900 to 1000 C for 20 to 60 minutes. This reflow step also acts to diffuse the n-type dopants implanted earlier, producing N+ source regions 212, which extend to a depth of 0.3 to 0.5 microns from the epitaxial layer surface and have net doping concentrations ranging, for example, from 1×10^{19} to $1 \times 10^{20} \text{ cm}^{-3}$.

[0052] After providing a patterned masking layer (not shown), the structure is then etched, typically by reactive ion etching, removing BPSG and oxide portions that are not protected by the masking layer. This step forms distinct BPSG regions 216 and distinct oxide regions 210.

[0053] The resist layer is then stripped, and a layer of doped polycrystalline silicon is provided over the structure, preferably using CVD. As above, the polycrystalline silicon is typically doped N-type to reduce its resistivity. Preferred resistivities range from 1 to 15 ohm/sq. The polycrystalline silicon layer is then blank etched (i.e., etched without a mask), for example, by reactive ion etching. Etching is conducted until portions of the upper surface of the epitaxial layer are exposed, with distinct polycrystalline silicon regions 215 remaining adjacent the sidewalls of the BPSG regions.

[0054] Boron is then implanted through the apertures found between the polycrystalline silicon regions 215 in both a low energy implant step and a high-energy implant step. For example, the structure can be subjected to a high energy implantation with boron at 100 to 200 keV with a dosage of 2×10^{13} to 2×10^{14} , followed by a low energy implantation with boron at 20 to 50 keV with a dosage of 5×10^{14} to 1×10^{15} . Alternatively, the low energy implantation can precede the high energy one.

[0055] The structure is then subjected to a rapid thermal annealing (RTA) step, for

example, 900 to 1100 degrees C for 1 to 2 minutes. This step diffuses the high- and low-energy-implanted boron to their final distributions, forming deep P+ regions 204d and shallow P+ regions 204s, respectively. As noted above, the deep P+ regions 204d typically extend, for example, from 0.4 to 1 microns in depth from the upper surface of the epitaxial layer and have a net doping concentration ranging, for example, from 1×10^{14} to $1 \times 10^{16} \text{ cm}^{-3}$. At the same time, the shallow P+ regions 204s typically extend, for example, from 0.2 to 0.4 microns in depth from the upper surface of the epitaxial layer and have a net doping concentration ranging, for example, from 1×10^{15} to 1×10^{17} . The resulting structure is illustrated in Fig. 4D.

[0056] As seen by comparing Fig. 5A with 5B, the width of the polycrystalline silicon regions 215 can be increased by increasing the height of the BPSG regions 216. This technique is effective, because the shapes of the polycrystalline silicon regions 215 are relatively similar (from a geometric standpoint), even though the heights of the BPSG regions 216 may differ. BPSG region 216 heights of 0.3 to 0.6 micron and polycrystalline silicon region 215 widths of 0.1 to 0.3 micron are typical.

[0057] At this point, a metal contact layer is normally deposited, resulting in a structure like that illustrated in Fig. 3A. The metal contact layer provides metal contact portion 218 as illustrated. Gate and drain contacts (not shown) are also typically provided.

[0058] Although various embodiments are specifically illustrated and described herein, it will be appreciated that modifications and variations of the present invention are covered by the above teachings and are within the purview of the appended claims without departing from the spirit and intended scope of the invention. As one specific example, the method of the present invention may be used to form a structure in which the conductivities of the various semiconductor regions are reversed from those described herein.